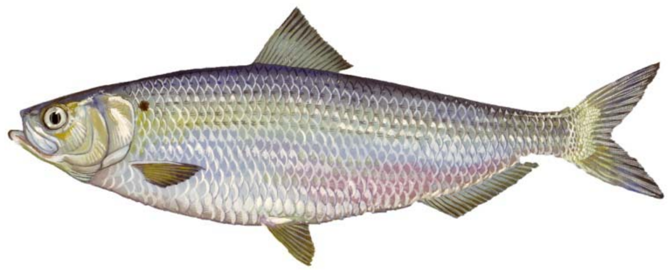
RIVER HERRING CLIMATE CHANGE WORKSHOP REPORT

River Herring: Alewife (*Alosa pseudoharengus*) and Blueback Herring (*Alosa aestivalis*)



Alewife (left) and blueback herring (right) images courtesy U.S. Fish and Wildlife Service

Prepared by the

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River Herring Workshop
Possible Climate Change Impacts to Alewives and Blueback Herring

July 18-19, 2012

Workshop Members

- Mike Alexander, NOAA Office of Oceanic and Atmospheric Research (OAR)
- Mike Bailey, U.S. Fish & Wildlife Service (USFWS)
- Karen Capossela, Maryland Department of Natural Resources (MDDNR)
- Hugh Carberry, New Jersey Division of Fish & Wildlife (NJDFW)
- Brad Chase, Massachusetts Division of Marine Fisheries (MADMF)
- Mathias Collins, NOAA National Marine Fisheries Service (NMFS)
- Jamie Cournane, University of New Hampshire (UNH)
- Mike Dionne, New Hampshire Fish and Game (NHF&G)
- Katie Drew, Atlantic States Marine Fisheries Commission (ASMFC)
- Claire Enterline, Maine Department of Marine Resources (ME DMR)
- Jon Hare, National Marine Fisheries Service (NMFS)
- Julie Harris, North Carolina Cooperative Fish and Wildlife Research Unit, (NC CRU)
- Adrian Jordaan, State University of New York (SUNY)
- Jacob LaFontaine, U.S. Geological Survey (USGS)
- Wilson Laney, U.S. Fish & Wildlife Service (USFWS)
- Amy Larimer, North Carolina Division of Marine Fisheries (NCDMF)
- Robert Lent, U.S. Geological Survey (USGS)
- Karin E. Limburg, State University of New York (SUNY)
- Patrick Lynch (Integrated Statistics, under contract by NOAA & EPA)
- Steve Markstrom, U.S. Geological Survey (USGS)
- Steve Miller, Great Bay National Estuarine Research Reserve (Great Bay NERR)
- Ru Morrison, Northeastern Regional Association of Coastal and Ocean Observing Systems (NERACOOS)
- Janet Nye, Environmental Protection Agency (EPA)
- Bill Post, South Carolina Department of Natural Resources (SCDNR)
- Fritz Rhode, NOAA National Marine Fisheries Service (NMFS)
- Roger Rulifson, East Carolina University (ECU)
- Charles Stock , NOAA Office of Oceanic and Atmospheric Research (OAR)
- Karen Wilson, University of Southern Maine (USM)
- Bennett Wynne, North Carolina Wildlife Resources Commission (NCWRC) (webinar only)

NMFS Staff

Diane Borggaard (organizer), Jon Hare (co-organizer), Kim Damon-Randall, Fritz Rohde, Mathias Collins, Sarah Laporte, Dan Kircheis, Tara Trinko-Lake, Edith Carson (notetaker, July 18-19), Kiersten Curti, Carrie Nordeen (notetaker, July 18), Aja Szumylo (notetaker, July 19)

Facilitator

Ken LaValley, New Hampshire Sea Grant

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Introduction

On August 5, 2011, NOAA's National Marine Fisheries Service (NMFS), received a petition from the Natural Resources Defense Council (NRDC), requesting that we list alewife (*Alosa pseudoharengus*) and blueback herring (*Alosa aestivalis*) each as threatened throughout all or a significant portion of their range under the Endangered Species Act (ESA). In the alternative, they requested that NMFS designate distinct population segments (DPS) of alewife and blueback herring as specified in the petition (Central New England, Long Island Sound, Chesapeake Bay and Carolina for alewives, and Central New England, Long Island Sound, and Chesapeake Bay for blueback herring). The petition contained information on the two species, including the taxonomy; historical and current distribution; physical and biological characteristics of its habitat and ecosystem relationships; population status and trends; and factors contributing to the species' decline. The petition also included information regarding the possible DPSs of alewife and blueback herring as described above. The petition also addressed the five factors identified in section 4(a)(1) of the ESA: (1) present or threatened destruction, modification, or curtailment of habitat or range; (2) over-utilization for commercial, recreational, scientific, or educational purposes; (3) disease or predation; (4) inadequacy of existing regulatory mechanisms; and (5) other natural or man-made factors affecting the species' continued existence.

NMFS reviewed the petition and published a positive 90-day finding on November 2, 2011, determining that the information in the petition, coupled with information otherwise available to the agency, indicated that the petitioned action may be warranted. As a result of the positive finding, the agency is required to review the status of the species to determine if listing of alewife and blueback herring (collectively referred to as river herring) under the ESA is warranted.

The Atlantic States Marine Fisheries Commission (ASMFC) completed a stock assessment for river herring in May 2012, covering over 50 river specific stocks throughout the species U.S. range (ASMFC, 2012). This represented a significant effort on behalf of the ASMFC and the coastal states from Maine to Florida. NMFS recognized this extensive effort to compile the most current information on the status of these stocks throughout their range in the United States and, working cooperatively with the Commission, utilized this information in the review of the status of these two species. Because the stock assessment did not contain all elements necessary for making a listing determination under the ESA, NMFS identified the missing required elements and held specific workshops focused on addressing this additional information. The three workshops addressed alewife and blueback herring stock structure, extinction risk analysis (ERA), and climate change. NMFS compiled reports from each workshop and working group meeting to determine which extinction risk method and stock structure analysis would best inform the listing determination. These reports do not contain any listing advice or reach any ESA listing conclusions – such synthesis and analysis is solely within the agency's purview. NMFS will use these reports along with the ASMFC river herring stock assessment to develop a listing determination.

Climate Change Workshop Description

To obtain expert opinion on the potential impacts of climate change on river herring in U.S. and Canadian freshwater and marine habitats along the East Coast of North America, NMFS convened a workshop in Gloucester, MA on July18-19, 2012. This workshop was open to the public and brought together experts from state and federal fisheries management agencies and academic institutions with experience in: 1) climate science; and/or 2) population dynamics and life history of anadromous species; and/or 3) assessing impacts of climate or environmental change on fish. Participants with fisheries expertise were selected to represent both freshwater and marine areas based on the expansive coast-wide range of river herring. While no consensus was sought or reached at the workshop, invited experts provided their individual opinion on the potential impacts of climate change on alewife and blueback herring based on the discussions from the meeting. The workshop also included opportunities for public contribution. Additionally, the public contribution period was extended for a week following the workshop to allow for additional submissions.

Overview

The goals of the workshop were as follows: 1) review climate science and river herring research relevant to climate change assessments from Atlantic Canada through Florida; 2) review ongoing quantitative (e.g. modeling) and qualitative (e.g. vulnerability assessments) approaches to assessing impacts of climate change on river herring habitat and population dynamics; 3) discuss possible impacts of climate change on river herring; and 4) identify research gaps for improving the assessment of climate impacts. Participants had an opportunity to provide both presentations at the workshop and a one-page overview as supplemental information for the workshop. It is important to note that the Department of Fisheries and Oceans Canada (DFO) was an invited participant but was unable to attend. However, several invited participants did have expertise in Canadian river herring management and research which was included in the presentations and discussions.

The workshop was structured to included presentations, panel discussion, group discussion, as well as public contribution. Given the broad geographical range and expertise of the participants, presentations included background information to ensure participants had a larger understanding of both the management and research surrounding river herring and climate change. Group discussion on possible mitigation ideas for climate change, and future stakeholders important to river herring and climate change impacts were also discussed. Additional information contributing to the topic was received from participants following the meeting. While a large amount of information on both river herring and climate science was presented during the two day meeting, this report focuses primarily on the information presented, discussed and/or provided (including information provided before or after the workshop) which assist in answering questions related to possible impacts of climate change on river herring. This workshop report incorporates text from the participant's presentation and/or written contributions (either in its entirety or in summary form received before, during or following the workshop), and includes verbal contributions made by participants during the meeting. Additional specifics on the information included in the summary (including supporting presentation graphics), and other information received is available through the presentations and supplemental information at NMFS' Northeast Regional Office Protected Resources Division river herring website (http://www.nero.noaa.gov/prot_res/CandidateSpeciesProgram/RiverHerringSOC.htm).

River Herring Life History Requirements

Spawning and Migratory Temperatures and Times

Karen Wilson (University of Southern Maine)

Wilson provided an overview of river herring life history and noted temperature is an important river herring spawning and migration cue. For example, she noted that adult river herring move up coastal rivers in early to late spring in response to water temperature. She also noted that temperature has important energetic implications for river herring as the warmer the water, the more energetically costly it is for the fish to linger in that water.

Wilson developed tables summarizing information on temperature and salinity preferences, and referenced Collette & Klein-MacPhee (2002) for a review (Table 1 and Table 2).

Temperatures preferences:

Wilson noted that spawning migration of blueback herring is later than alewives which could be a temperature trigger. Wilson noted in here presentation that there is some newer information which could be used to supplement Table 1 below at a future point.

Table 1. Temperature tolerances table as seen in Wilson's presentation

	Alewife	Blueback	Source
Spawning migration	Begins ~ 5 - 10 °C [a] Temps < 8 °C and > 18 °C = little adult movement [b] Light & flows also important [b,c]	Begins ~ 10 – 15 °C [a] NS rivers: 13-21 °C [ee] Later than ALE when sympatric.	(a) Loesch 1987 (b) Richkus 1974 (c) Collins 1952 (ee) Crawford et al 1986
Spawning	10 – 20 °C [d,e] Males arrive before females; larger & older spawn first	Optimal 21-25 °C [aa-cc] Min 14 °C, max < 27 °C [dd] NS Rivers : 20-22 °C [ee]	(d) Rounsefell and Stringer 1943 (e) Carlander 1969 (aa) Cianci 1969 (bb) Marcy 1976b (cc) Klauda et al 1991 (dd) Loesch 1968
Egg incubation	Optimal 17-21 °C 2-3 days @ 22 °C 6 days @ 15.6 °C [d,f,g]	3-4 days @ 20-21 °C [g] 55-58 hrs @ 22.2-23.7 °C [aa,cc]	(f) Mansueti 1956 (g) Jones at al 1978
Hatching success	Max at 20.8 °C, ceases at 29.7 °C [h,i,j]		(h) Edsall 1970 (i) Marcy 1971 & 1973 (j) Kellogg 1982
Larval survival	Minimal above 28 °C [h, i]	Minimal above 28 °C [h, i]	

Salinity Preferences:

Wilson noted that blueback herring are able to tolerate much higher salinities which support their rapid movement into the estuary. She noted that both alewife and blueback herring can become landlocked, and both juveniles and adults have the ability to move back and forth between fresh and salt water without much physiological impact giving them greater life history flexibility than other species such as salmon.

Table 2. Salinity tolerances table as seen in Wilson's presentation

	Alewife	Blueback	Reference
Larval tolerances	??	Eggs & larvae tolerate up to 18-22 ppt [a] Juveniles can use both FW & estuarine habitats up to 28 ppt [b]	(a) Johnston & Cheverie 1988 (b) Chittenden 1972b
Adult	FW <–> salt land-locked populations are common [often introduced]	FW <–> salt some land-locked populations reported (e.g., Cooper-Santee river system in SC)	

Patrick Lynch (Integrated Statistics,under contract by NOAA & EPA)

Lynch provided information from Ellis and Vokoun (2009) which showed that 13°C stream temperature was a predictor for alewife run timing in several southern New England streams.

Jamie Cournane (University of New Hampshire)

Cournane presented on Canadian Maritimes fisheries management, noting that most Canadian Maritime fisheries target alewife due to bait demands matching earlier spawning timing of alewife rather than blueback herring. Cournane noted that Stone and Jessop (1992) conducted an analysis of oceanic trawl survey data collected between 1970 and 1989, and concluded that oceanographic features strongly tie to river herring distributions at sea. Cournane noted that the research indicated that river herring were most abundant in spring in the warmer deeper waters of the Scotian Shelf; occurred in the Bay of Fundy and off southwestern Nova

Scotia in spring, summer and fall surveys, in places with strong tidal mixing and upwelling; and were rarely found on the eastern Scotian Shelf.

Roger Rulifson (East Carolina University) and Wilson Laney (U.S. Fish and Wildlife Service)

Rulifson and Laney provided information from Smith (2006) which reported alewife were first observed spawning in the Tar River on March 12, 2004, and alewife spawning ended on May 17 for a total of 67 days. During this time they noted three spawning peaks: March 29, April 5, and May 14, 2004. The water temperatures during the spawning run ranged from 12.4 to 17.9 °C. In 2005, alewife spawning was first observed on April 22, but it lasted only 4 days ending on April 25, 2005. They noted water temperatures during the four-day period were 13.7 to 20.2 °C. Rulifson noted that the blueback herring run is vestigial at best. Spawning was observed on May 17, 2004, with water temperature at 21.2 °C and on April 11, 2005, with water temperature at 17.6 °C.

Julianne Harris (North Carolina State University)

Harris presented on aspects of life history for blueback herring in the St. Johns River, Florida, during spawning migrations from 2002-2005 (McBride *et al*., 2010). She noted that the St. Johns River is the southern extent for spawning by blueback herring and provides a unique opportunity to examine life history for the species where it does not co-exist with alewife. She stated that blueback herring were collected in the St. Johns River from January to April and histological examination of gonads suggested that most spawning occurred from February to April, with most of the spawning occurring in April. Harris reported that some gravid females were collected almost 400 km from the river mouth. Although specific spawning sites were not identified, Harris believes that the data suggest that spawning may occur at multiple sites in the river. Therefore, she summized that blueback herring appear to be batch spawners and may spawn batches of eggs every 3-4 days during the spawning period.

<u>Marine Temperatures and Times</u>

<u>Karen Wilson (University of Maine)</u>

Wilson provided information from Neves (1981) which concluded from NMFS bottom trawl survey data (1963-1978) that alewives are most frequently found in marine areas where water temperatures range from 3 to 17 °C and blueback herring from 2 to 12 °C and 16 °C. Wilson noted that this study suggested that populations south of Cape Hatteras would migrate from the north along the coast to avoid 17.5 °C thermal barrier located offshore year round.

Wilson also provided information from Stone and Jessop (1992) which concluded from various temporal and spatial Canadian groundfish bottom trawls (1970-1989) that most catches occurred at > 5 °C.

<u>Patrick Lynch (Integrated Statistics,under contract by NOAA & EPA)</u>

Lynch presented preliminary results of a recent study that suggested the preferred spring and fall sea surface temperature ranges were similar for alewife (spring: 2.2 to 6.2 °C; fall: 3.8 to 9.8 °C) and blueback herring (spring: 2.2 to 6.2 °C; fall: 8.8 to 10.8 °C).

<u>Jamie Cournane (University of New Hampshire)</u>

Cournane presented on a spatially-explicit model of anadromous alosine hotspots at sea that uses seasonal NMFS bottom-trawl survey data.   She reported that in general, patterns of seasonal river herring hotspot areas reflected river herring at sea migratory patterns, traveling south to north from winter through fall, presumably due to temperature fluctuations and food availability, and then returning south to overwinter. She noted that winter river herring hotspots included quarter degree squares in Southern New England waters and in the Northern Mid-Atlantic Bight. Spring river herring hotspots included quarter degree squares throughout the US Eastern Continental Shelf with the exception of Georges Bank. Summer river herring hotspots roughly followed the 100 meter (m) bathymetric contour, from Southern New England waters northward to the waters of Downeast Maine. She noted that river herring fall hotspots were nearly exclusively north of Cape Cod with two exceptions in Southern New England Waters.

Temperature and Osmoregulatory Physiology

Eric Schultz (University of Connecticut

Eric Schultz (who was unable to attend the workshop) provided information on environmental tolerances that might be useful in parameterizing upcoming modeling efforts following the meeting. He provided a reference by McCormick *et al*. (1997) which researched temperature effects on osmoregulatory physiology of juvenile anadromous fish. McCormick *et al.* (1997) found mortality of alewives in freshwater at cold temperatures (5°C) similar to findings of Stanley and Colbey (1971). McCormick *et al.* also reported that ion regulation was not significantly affected by temperature up to 31° C in either fresh or sea water so that in their normal geographical range, osmotic tolerance of alewives are not likely to be negatively affected by global warming. Alewives can regulate ions at the end of their migratory period even at high temperatures (McCormick *et al*., 1997). Although impacts on increased temperatures on food resources and predators is difficult to predict, global warming may have a positive effect on anadromous clupeids (e.g. river herring) from a physiological perspective by allowing northern range expansion and increased growth opportunities in freshwater (McCormick et al., 1997).

Schultz provided data on salinity tolerance of anadromous and landlocked alewives (conducted in collaboration with McCormick and Velotta, see supplemental information for this meeting which can be found at the website noted in the "Overview" section above). This study design included the capture of juvenile alewives from six landlocked and one anadromous location in Connecticut during summer and autumn which were subjected to freshwater and saltwater for 24 hours. The study concluded that anadromous fish are more tolerant of ocean-level salinity than landlocked fish which was linked to various aspects of osmoregulation. This study also tested multiple salinity levels (for two weeks following a one month acclimation period) on juvenile alewives from two of the landlocked locations and the anadromous location. The results indicated that: 1) survival was highest in alewives from one of the landlocked locations at 0 parts per thousand (ppt), while there was no difference in survival at 30ppt; 2) survival was lowest among landlocked sites at 35ppt and 40ppt; and 3) freshwater and saltwater tolerance differed among landlocked sites.

Additional Considerations

Karen Wilson (University of Maine)

- Water Flows: Wilson noted that water flows dictate, in large part, the ability of fish to pass both natural and anthropogenic barriers in rivers. According to Wilson, either too much or too little flow can render fish passage ineffective, delay fish at a barrier long enough as to deplete the fish's energy stores before spawning, or prevent a spawned-out fish from reaching the ocean. She also noted that outmigration is also impacted by flows (e.g., greater flows may ease outmigration by reducing time spent, minimal flows may block outmigration of young of year in late summer and fall).

Climate Change in North Atlantic

Observed and Predicted Climate Variability and Change

Mike Alexander (NOAA Earth System Research Laboratory)

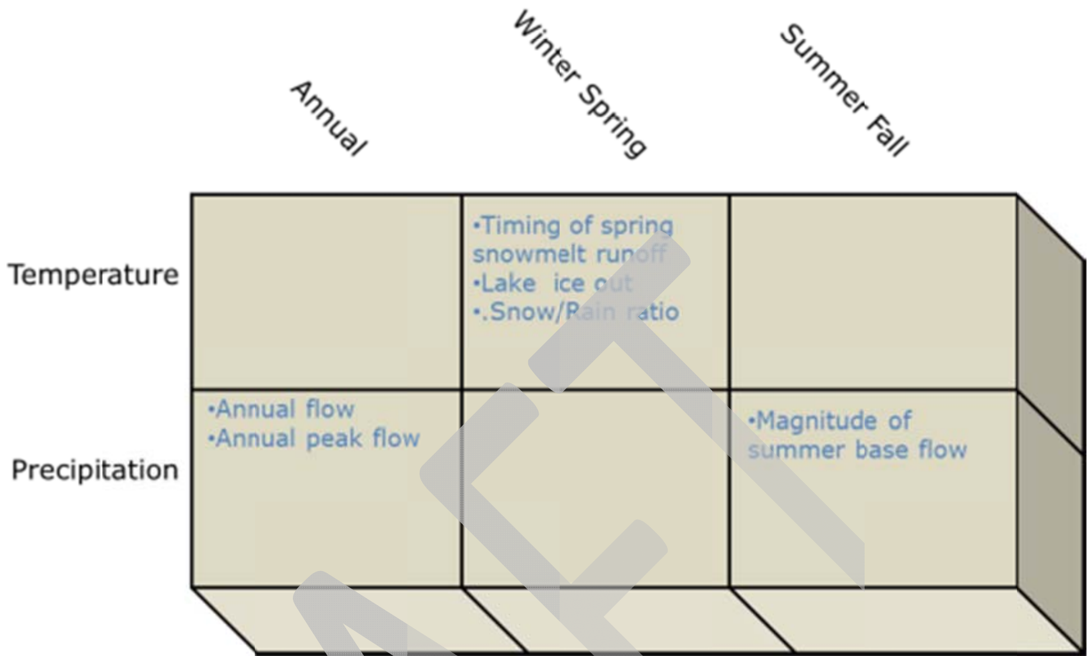
Alexander noted that because river herring are anadromous, they are influenced by climate variability and change both in freshwater and marine environments. He presented climate model results from the Intergovernmental Panel on Climate Change (IPCC) 4th assessment indicating an increase in the surface and 200 m temperature during the 21st century over most of the global oceans including the northwest Atlantic. Alexander provided information on salinity in the Atlantic that suggests it will increase in mid-latitudes (up to ~45°N) and decrease over portions of the subarctic. Alexander stated that due to temperature and salinity changes enhancing the stratification in the North Atlantic, the mixing of nutrients (not currently included in the IPCC models) into the surface waters may be impeded.

Alexander noted that results from the North American Regional Climate Change Assessment Program (NARCCAP; uses fields from the global climate models to provide boundary conditions for regional atmospheric models covering most of North America and extending over the adjacent oceans) suggest that temperature will warm throughout the year over the northeast, mid-Atlantic and Southeast US. Alexander noted that there is an expected increase in precipitation over the northeast US during fall and winter, though stated that because of high variability among the simulations the rainfall prediction is more uncertain. However, based on this, Alexander noted that runoff (a rough estimate of river flow) decreases which is likely due to an increase in evaporation. Alexander also noted that models predict reduced snow depth in the northeast and earlier snow melt although there is a large spread in the simulations. Subsequently, in conjunction with increased evaporation from warmer temperatures, the Northeast and mid-Atlantic may experience decrease in runoff and decreased stream flow in late winter and early spring.   Alexander went on to add that enhanced ocean stratification could be caused by greater warming at the ocean surface than at depth.

Robert Lent (United States Geological Survey)

Lent presented on hydrologic and water temperature response to climate variation in New England. He noted that New England's climate is very sensitive, and is responding to climate change in a number of ways and on a number of different time scales. Lent noted that spring runoff dominates the annual hydrograph, is occurring significantly earlier in northern New England in recent years, and timing is related to air temperature (and not precipitation patterns) (Hodgkins and Dudley, 2006).   He noted that snowmelt runoff used to have the most effect on spring river flows (Hodgkins *et al*., 2003), but it is now a function of precipitation. Lent also provided some New England hydrological variables that respond to climate change:

Table 3. New England variables table as seen in Lent's presentation



Lent indicated that USGS has found effects of climate change on eutrophication on hypolimnetic oxygen demand in lakes. He also noted that temperature gauges were limited in the Northeast, but that there have been recent studies to estimate both river water temperature and lake-surface water temperature from air temperature (e.g. Sheepscot River Atlantic salmon, Spednic Lake).

Mathias Collins (NOAA Restoration Center)

Collins presented on regional flood trends and relevance for river herring habitat. He suggested that climate variability/change is affecting flood flows region-wide based on recent research in the Northeast United States showing increased flood magnitudes and frequencies in watersheds minimally impacted by human development (Armstrong *et al.*, 2012; Armstrong *et al.*, In review; Collins, 2009; Hodgkins, 2010; NOAA, 2011). Collins summarized analyses of flood data from climate-sensitive stream gauges with long records in the northeast United States and Atlantic Canada, and noted that this suggests that small, frequent floods have been disproportionately affected by regional hydroclimatic change. He noted that larger and more frequent floods over last decade appear to be part of a hydroclimatic step increase that began around 1970. Collins stated that high frequency floods are very important for forming stream channel geometry (e.g. Slater and Singer, 2011), and thus stream channel habitat. Collins thought that climatically-induced changes add to and magnify similar changes brought about by watershed urbanization.

Jon Hare (NOAA/NMFS/Northeast Fisheries Science Center)

Hare presented on ocean climate (temperature and acidification) and river herring. He noted that temperature is a dominant factor affecting organisms in many ways (Fry, 1971), and therefore, is an important physical parameter to consider in such assessments. Hare presented information and stated that temperatures will likely increase in the ocean (e.g. shelf), estuaries and rivers (e.g., Nixon *et al.*, 2004; Shearman and Lentz, 2010). He also provide information that salinity has been decreasing since 1977 in the Georges Bank region as a result of an increase in freshwater (ice melt or run off) coming from Nova Scotia (e.g. Mountain, 2004; Greene and Pershing, 2007). Hare noted there is a strong linear correlation between monthly water temperature and monthly air temperature, so air temperature can be a useful proxy for estuarine temperature (Hare and Able, 2007) and stream water temperature (Pilgrim *et al.*, 1998) as convection is more important in shallower environments. Lastly, Hare noted that in respect to temperature, an ongoing study he is involved in indicates that with an increase in carbon dioxide (CO_2) there will be an increase in estuarine winter temperature.

Hare noted that as CO_2 increases in the atmosphere it absorbs into the ocean, so CO_2 increases in the ocean. He added that CO_2 is a weak acid that decreases the pH of the ocean. Hare stated that the atmospheric carbonate chemistry is an important consideration of calcification and ocean chemistry due to: direct effects (e.g., development, olfaction), indirect effects (e.g., prey impacts, predator impacts) and community effects (e.g., primary productivity). Hare noted that currently there is no specific information on impacts of ocean acidification on river herring. However, he discussed some potential effects such as the development in shellfish and fish, and chemical signaling (olfaction) which could be important for river herring. Hare also noted that river herring prey could be vulnerable to acidification due to de-calcification.

Hydrology Modeling

Many workshop participants believed that the United States Geological Survey (USGS) hydrology modeling efforts detailed below are important to consider when assessing impacts of climate change to river herring. Additionally, the use of these models for all U.S. watershed systems was encouraged.

Steve Markstrom (United States Geological Survey)

Markstrom presented on the importance of effective stream temperature modeling, related to determination of suitability and management of ecological habitat which USGS has demonstrated through various studies. He noted that watershed hydrology models have been used to project the hydrologic response of watersheds to a variety of changing climatic and land-use scenarios by coupling two models. Markstrom stated that these models incorporate the following considerations: 1) precipitation, climate, and land use on watershed response whereby normal and extreme rainfall and snowmelt responses can be simulated to evaluate changes in water-balance relations, streamflow regimes, soil-water relations, and groundwater recharge (Precipitation-Runoff Modeling System simulation model); and 2) predicted in-stream water temperatures based on hydrological, meteorological, topographic and vegetative shading, and stream channel conditions (StreamNetwork Temperature simulation model). Markstrom provided where the software, documentation and examples are available (http://wwwbrr.cr.usgs.gov/mows). (Note: Jacob LaFontaine from USGS presented on how these two models have been applied together in a study of the Apalachicola—Chattahoochee—Flint River Basin in the southeastern U.S. as part of the U.S. Geological Survey Southeast Regional Assessment Project. See supplemental information and powerpoint for additional specifics which can be found at the website noted in the "Overview" section above.) He also noted that a paper on the evaluation of global climate models/scenarios in regards to stream temperature is in preparation.

Observed Climate or Environmental Impacts on River Herring

Jamie Cournane, University of New Hampshire

Cournane noted that Stone (unpublished data) recently plotted multi-year composites of alewife distribution and relative abundance (average weight (kg)/tow aggregated by 5 minute squares) for summer DFO oceanic trawl surveys. She added that changes in both distribution and relative abundance are evident from visual inspection and remain the subject of further examination. Cournane questioned whether this was related to a climate shift and/or decreased fishing effort.

Katie Drew (Atlantic States Marine Fisheries Commissions)

Drew noted that the regional differences were seen in some of the fishery independent indices used in the Atlantic States Marine Fisheries Commission (ASMFC) River Herring Stock Assessment (ASMFC, 2012); for example, trawl surveys in southern regions were more likely to be below the 25^{th} percentile of the time-series than trawl surveys from northern regions (i.e. the number of positive tows become higher in the north and less in the south over time). However, Drew cautioned that it is difficult to distinguish between differences in trends that result from climate change and those that result from differences in management exploitation, habitat loss, and other factors at the stock level.

Karen Wilson (University of Southern Maine)

Wilson noted that in the spring of 2012, many spawning runs in northern states began 2-3 weeks earlier than normal which were correlated with unusually warm spring temperatures. In more northerly rivers, Wilson noted that it is not uncommon for water temperatures to drop due to spring storms and for fish to “fall back” into estuaries or larger rivers. She added that changes in the timing of spawning may contribute to “match – mismatch” between predator and prey.

Claire Enterline (Maine Department of Marine Resources)

Enterline noted that although the St. Croix population has recently declined due to fish passage closure, data before the closure may provide information about how climatic changes may have impacted the population. Trends in the number of returning adults in a given year seem to have a relationship with spring and fall discharge 4-years prior (both species are fully recruited at age-4). Enterline also noted Maine does conduct outmigration surveys. She noted that they have observed earlier migrations although the surveys are not standardized. For example, Enterline reported that in the Androscoggin River where there are daily surveys, that outmigrations are observed to occur earlier (e.g. July 4, 2012, survey).

Karin Limburg (SUNY College of Environmental Science & Forestry)

Limburg noted that hypoxia could be a climate change impact to juvenile river herring in the freshwater phase. She noted that this may be a concern for Chesapeake Bay, and western Long Island Sound which has historically had hypoxia events.

Limburg also cited work done in Rhode Island on juvenile alewives which found earlier emigration (Richkus, 1974). She hypothesized that more powerful rain events over time might be an environmental cause.

Roger Rulifson (East Carolina University) and Wilson Laney (U.S. Fish and Wildlife Service)

Wilson and Laney provided information on the Lake Mattamuskeet National Wildlife Refuge in the North Carolina Coastal Plain which they described as historically hosting a spawning run of alewife, and possibly blueback herring (Tyus, 1971; H. Tyus, pers. comm. to Laney), and currently constitutes nursery habitat for alewife. Based on historic data on the alewife run (Tyus 1971) and more recent work examining fish passage into the Refuge (Wall, 2003; Godwin, 2004), Rulifson noted that spawning was later in the season in the 1970s and at cooler water temperatures then the spawning run of the late 1990s-early 2000s. Rulifson and Laney provided the below to support this statement:

- Tyus (1971) reported a relatively healthy population in 1970 of an estimated 199,633 individuals running in Lake Landing Canal with a peak spawning time of April 5-6 at a temperature of 12.9°C. In 1971, the Lake Landing Canal population had dropped to an estimate of 167,300 individuals with the peak spawn on April 2-3 at a temperature of 13.1°C.
- Twenty-seven years later, Wall (2003) reported that the total alewife run in 1997 in lake Landing Canal was only 178 individuals, and in 1998 only 454 fish. Once new flapgates of the original design were installed, Godwin (2004) reported an estimated 8,836 fish through Waupoppin Canal between March 14-May 6 in 2001.
- In 2003, the Waupoppin Canal spawning run occurred February 21 through May 1 with the peak during March 23-29 at a temperature of 18.4° C. The spawning run had increased to 38,731 fish. In Lake Landing Canal, the run was from February 26 to April 30, 2003, but the run size could not be estimated.

Rulifson and Wilson pointed out that the over 40 years of water level data at the Refuge showed the rise in water level during that period. They also believed that North Carolina was in a severe drought during the late 1990s and early 2000s, which could have forced earlier spawning at higher temperatures.

Rulifson also noted during discussions that drought conditions impacted spawning runs in Lake Norman, North Carolina. He noted that during the 1970s spawning occurred at 7° C late in the season, in the 1990s it was 12° C in February/March, and occurred at 18° C during the drought period.

Bennett Wynne (North Carolina Wildlife Resources Commission)

Wynne provided information following the workshop from a 1968 report of the North Carolina Wildlife Resources Commission Division of Inland Fisheries (NCWRC, 1968). This report noted that river herring were not distinguished between the two species during the survey; however, alewife and blueback herring ranges were estimated through comparisons of watersheds and whether the rivers emptied into sounds or directly into the ocean. It was determined that watersheds from the Neuse River north contained both alewife and blueback herring, though south of the Neuse River where rivers primarily emptied into the ocean, contained alewife predominantly, with blueback herring being considered uncommon. From this report Wynne noted that in the Cape Fear River system in the 1960s, alewife were more common than were blueback herring. Currently and in recent years, alewife have not been observed in this system, though blueback herring spawning runs have been observed and are persisting in these lower tributaries (e.g., Town Creek). However, these blueback herring spawning runs were not included in the report for known for river herring distribution in 1968. Furthermore, Cape Fear river herring in 1968 were considered to consist primarily of alewife, which contrasts with recent years data which implies that alewife are no longer present in this system. Wynne noted that the North Carolina Museum Fish Collection database confirmed these records, indicating alewife occurrence in the Cape Fear system from the 1950s to the 1970s; however, blueback herring occurrence was not indicated till the 1980s and later. Wynne hypothesized that if alewife and blueback herring evolved at differing latitudes, then with the passing of geologic time, and as both species populations decline, potential temperature changes could occur which might accentuate the species differences and may lead to the ranges of the species to begin separating from one another.

Julianne Harris (North Carolina State University)

Harris relayed information on blueback herring in Florida (2002-2005) noting that they spawn during the coldest time of the year (January – April) and peak during the coldest temperatures around 16 to 19 °C. The window in which these temperatures are occurring is getting shorter and shorter.

Brad Chase (Massachusetts Division of Marine Fisheries)

Chase presented information on environmental monitoring related to river herring populations and habitats in Massachusetts. He discussed MADMF's efforts using a Quality Assurance Program Plan (QAPP; Chase, 2010) for river herring habitat assessments began in 2008. Chase noted that the results to date have documented periodic impairment due to high water temperature, low pH, and low water clarity; and more common impairment from low dissolved oxygen, low stream flow, and high nutrients (TN and TP). In urban settings, the common presence of hypolimnetic anoxia raises concerns over limitations on river herring nursery habitat.

Chase noted that water temperature loggers have been deployed at marine stations off the coast of Massachusetts since the mid-1980s and in rivers where diadromous fish are monitored since 2002. Chase stated that these ongoing efforts along with readily available data sources on local environmental conditions will contribute to analyses of long-term run count data. He provided an example of a multiple regression model developed for the Monument River where a variety of covariates were analyzed with 30 years of spawning run count data. Chase noted that the best model for predicting recruitment (4 and 5 year lag) was most influenced by fall precipitation.

Eric Schultz (University of Connecticut: presented by Ben Gahagan currently with MADMF)

Eric Schultz (who was unable to attend the workshop as a participant) provided information prior to the meeting indicating that migration timing is a life history feature responding to climate change. Gahagan (on behalf of Schultz) noted that pulses of outmigration of alewife juveniles from Bride Lake, a coastal pond in Connecticut, were associated with precipitation events, transient decreases in water temperature, and transient increases in stream discharge in 2006 (Gahagan *et al*., 2010). Additionally, he noted that outflows from some coastal ponds (e.g. Bride Lake) dry up during some summers (Gahagan *et al*., 2010), preventing the outmigration of alewife juveniles and potentially reducing their growth and probability of survival. Gahagan added that changes in climate, combined with changes in land and water use patterns, are likely to have pronounced and complex effects on juvenile prospects. He also provided information on a study by Ellis and Vokoun (2009) which used contemporary and historic data on the temperature-dependence of adult migration timing and estimated that alewife run timing has shifted 12-13 days earlier over three decades.

Fritz Rohde (NOAA Southeast Regional Office)

Rohde provided information at the workshop, and additional thoughts following the workshop on his observations in the Southeast Region. He noted that with the large coastal plain in the southeast and main stem dams being located hundreds of kilometers upstream, factors such as sea-level rise and higher temperatures would likely create more suitable river herring habitat rather than reduce it. He noted that some uncertainties in the area include precipitation (e.g. droughts) and more frequent heavy precipitation events (e.g. hurricanes and tropical storms) could either cause hypoxia or prematurely flush juveniles out of the rivers.

Bill Post (South Carolina Department of Natural Resources)

Post presented on potential changes of blueback herring in South Carolina due to climate change. He noted that sea level rise and the alteration of the saltwater/freshwater interface will impact diadromous fish in the area. Additionally, Post said that water quantity issues are a concern with the worst scenarios being sea level rise accompanied by drought. He noted water quantity issues include recruitment failure due to severe drought conditions that can dewater essential habitat; and absence of the seasonally elevated flows which serve as a cue for spawning migration. As far as temperature rise (e.g. 2012 warmer winter), Post said that this could affect spawning cues for diadromous species. He also noted that many of these species are already stressed by the timing of spring phytoplankton blooms that many larval and juvenile clupeid species depend on.

Tools to Assess Climate Impacts on River Herring, Including Any Preliminary Results

Otolith Chemistry

Karin Limburg (SUNY College of Environmental Science & Forestry)

Limburg presented information on emerging otolith microchemistry technology that can serve as natural tags of river herring provenance and climate change impacts. She noted that work is in progress to understand the influence of both internal (e.g., growth, genetics) and external (e.g. temperature, salinity) factors influencing elemental uptake in otoliths. She noted that the trace elements barium and strontium are taken up in proportion to ambient concentrations relative to calcium in the water, although temperature may also affect the uptake. Limburg noted the following:

- Oxygen isotopes are taken up in proportion to ambient concentrations, and because this is related to climate, oxygen isotopic ratios (delta ^{18}O) may serve as "internal thermometers" if salinity is known.
- Strontium isotope ratios ($^{87/86}$Sr) may serve as salinity markers, because the $^{87/86}$Sr signature of modern seawater is constant.
- Manganese to calcium ratios (Mn:Ca) in otoliths has been shown to correlate with intensity of hypoxia events (Limburg *et al.*, 2011).

Limburg stated that she is involved in the development of a "geochemical atlas" of otolith chemistries of the river herring coastwide populations, in conjunction with a genetic analysis (preliminary data were reported at the first river herring workshop on river herring stock structure). She noted that when combined with age and growth analysis, these data will be able to provide information on many early life history properties, such as age (in days) at first emigration to the sea, size of same, hypoxia exposure, and thermal history in the nursery habitat. However, Limburg added that sea experiences may be more difficult to discriminate at this point, but thermal records may be possible.

Habitat Models

Julianne Harris (North Carolina State University)

Harris presented on a Bayesian habitat suitability model, a technique developed for American shad (Hightower *et al*., In press), which she suggested could be used to examine potential impacts of climate change on river herring spawning habitat. She suggested that a similar modeling process, including data and expert opinion on important environmental variables (for each life state) for multiple systems, could be used to update habitat suitability models for both blueback herring and alewife. Harris noted that a clear understanding of habitat suitability for each species as well as potential changes to selected habitats as a function of climate change (e.g., potential shifts in temperature and discharge rates) would be important. She believed that integrating models with data and expert opinion could help evaluate the potential impacts of climate change on specific populations, as well as ecosystems as a whole.

Brad Chase (Massachusetts Division of Marine Fisheries)

Chase presented on MADMF efforts on anadromous (including river herring) habitat assessments (Chase, 2010; Chase *et al*., 2010) which provide examples of monitoring programs with identification of environmental relationships to population demographics as being one of the goals. He noted that MADMF river herring spawning run monitoring and habitat assessment projects rely on a QAPP (Chase, 2010) guidance to produce comparable and reliable water quality data. For example, Chase noted that the QAPP has Standard Operating Procedures on: water temperature loggers, water chemistry multi-probe sondes, smelt spawning habitat assessment and river herring spawning and nursery habitat assessment. Chase noted that studies such as this help further information on the physical criteria that relate to biological thresholds important to river herring life history.

Assessments

Jon Hare (NOAA/NMFS/Northeast Fisheries Science Center)

Hare presented on a NMFS vulnerability assessment that look at vulnerability of various fish species to climate change. This is an initiative being led by NMFS Office of Sustainable Fisheries. Hare noted that the components of vulnerability being looked at include exposure (direct and indirect effects of sea surface temperature, acidification, ocean circulation, freshwater input); sensitivity (physiological, change is larval survival and prey specificity) and adaptive capacity (stock range, stock mobility, reproductive potential, stock status). The outcome is a relative ranking of vulnerability for each species based on these components. Hare noted that rive herring are included in the list of species to be assessed which encompasses species from across various life histories. Although the results will be a relative ranking of vulnerability of one species against another, Hare noted that it will help to possibly direct more focused species studies in the future. He said that river herring will be discussed during a pilot phase of the project being conducted in August 2012, and will be included for the Northeast assessment of various management fisheries species in 2013.

Patrick Lynch (Integrated Statistics, under contract by NOAA & EPA)

Patrick Lynch presented on the preliminary marine results of a study estimating and projecting the effects of climate change on river herring populations in both freshwater and marine habitats. He noted that historical data is being used to explore relationships between river herring populations, habitats, and environmental variability with a focus on water temperature and river flow. Lynch added that downscaled global climate models are being used to project regional environmental changes in river herring habitats. He further explained that by linking projected environmental changes to river herring population models, they can predict the population response to future climate scenarios. Lynch reported on the environmental effects in marine habitat which has been the initial focus of the study. As noted above, he found that the preferred spring and fall sea surface temperature ranges were similar for alewife (spring: 2.2 to 6.2 °C; fall: 3.8 to 9.8 °C) and blueback herring (spring: 2.2 to 6.2 °C; fall: 8.8 to 10.8 °C). Additionally, the results indicate significant increases in mean latitude of occurrence for both species (i.e., northward distribution shifts similar to Nye *et al.*, 2009), increases in frequency and abundance (which shows discrepancy with river data), and deeper occurrences over time. Lynch noted that preferred thermal habitat is projected to substantially decrease in the NEFSC trawl survey area except for blueback herring in the fall. He theorized some possible implications including that river herring: 1) migrate to remain in preferred habitat; 2) tolerate less “suitable” habitat; 3) adapt to changing habitat; and 4) negative impact on population.

Lynch noted that they will be looking at the freshwater environment and considering discussions provided at the workshop. He also provided information from Ellis and Vokoun (2009) which showed that stream water temperatures reached 13° C, a cue to migration in several southern New England streams, earlier in recent years than they did in the 1970s.

Adrian Jordaan (State University of New York- Stony Brook)

Jordaan presented on a multivariate analysis looking at what the effects of run counts are over various variables including climate. Preliminary data (Jordaan and Kritzer, Unpublished data) showed normalized run counts of alewife and blueback herring have a stronger correlation with fisheries and predators than various climate variables.

Jordaan presented background and results looking at run counts and stream flow in New England. He noted that where there is good data on run counts there is limited information on flow rates. Furthermore, rivers with good run count data are most often are associated with fishways which can have considerable effects on return rates. Jordaan provided information on various outcomes of flow impacts because of fishways and dams. His results suggested that low flow in summer and fall 3 to 4 years prior to a fishway count can impact juvenile growth/survival and outmigration of juveniles after summer growth, respectively. Additionally, Jordaan reported that high spring flow in the year of data collection may reduce passage of fish due to a velocity barrier (although some may still spawn below the dam). He also noted that alewives and blueback herring respond differently to different flows.

Considerations Related to Assessing Climate/Environmental Impacts on River Herring

The below includes a list of comments made by participants either before or after the workshop that should be considered when assessing impacts of climate change to river herring. These comments were not necessarily made in response to this specific question, but are important considerations. Additionally, numerous data gaps for both alewife and blueback herring (see "Data Gaps" section below) were noted, which are important to consider.

- Drew noted that the ASMFC river herring assessment used both fishery-dependent and independent data as well as information about river herring biology and life history to assess the current status of alewife and blueback herring stocks on the Atlantic coast. Data from a total of 57 river and bay systems from Florida through Maine were included in this assessment. However, only 26% were considered to have complete data (e.g. including harvest size, age, trends in abundance, etc.), most of these occurring in the New England states. Additionally, she noted that multiple data sources from an individual river are not always available.
- Wilson noted that due to the population declines shown in the ASMFC stock assessment report (ASMFC, 2012), the residual populations may be more vulnerable to stochastic events.
- Wilson noted that river herring are natal spawners and home to the natal river system; however, there is some straying that may be occurring in freshwater systems.

- Enterline noted that in addition to the effect of climatic changes on populations, the ability of river herring to reach spawning habitat and the amount of available habitat must also be considered.
- Rulifson noted that spawning temperature information from the North Carolina Tar/Pamlico Watershed (Smith 2006; see additional information above) can provide a baseline for climate change and sea level rise. He thought that spawning and potential nursery habitats will be pushed upstream and squeezed against the dam as these two aspects increase later in the century.
- Cournane noted that since the early 1990s, little attention has focused on understanding river herring coastwide distributions at sea. However, she noted that improved understanding of these distribution patterns can provide a baseline to, amongst other purposes, compare suspected distributions under future climate and environmental conditions. She noted that quantitative assessments of climate change in the marine environment should incorporate nearshore surveys, as well as DFO oceanic trawl surveys in the Canadian Maritimes. Cournane provided a list of various Canadian river herring (Gaspereau) datasets in the supplemental information for future consideration.
- Chase and other participants suggested the development of standardized data collection and processing protocols for various types of sampling during diadromous fish monitoring to help with future assessments of climate (and other impacts).
- Hare noted that the USGS model is the preferred method for considering watershed impacts due to climate change, where available. However, air temperature can be used as a proxy where information is not available.

- Alexander cautioned that in nature there is a coming of nature and climate change. He added that even with long term changes, the natural climate system is able to make changes.
- Markstrom noted that scale is an important consideration when looking at regional and hydrological responses to climate change.
- Collins noted that urbanization considerations are important and they may amplify any climate/environmental impacts observed. He cautioned that sometimes it may be difficult to distinguish between an urbanization and climate impact.
    - Additional information from Limburg was submitted following the workshop on the effects of urbanization on juvenile alewife. Monteiro *et al*. (In prep.) showed evidence to indicate that urbanization of coastal watersheds may result in a reduction in survival of juvenile alewife to reproductive age. The study showed that juvenile alewives in Maine ponds grow faster to greater lengths and weights than do juvenile alewives in ponds on Cape Cod, MA. These findings could indicate that the urbanization of coastal watersheds results in less ideal habitat for juvenile alewives considering that impacted watersheds yielded slower growing juveniles in poorer condition, than watersheds not impacted by urbanization.
- Jordaan noted that as there has been historical habitat loss in Maine (95% since 1850) (Hall *et al*., 2012) and that populations have been pushed to a series of coastal ponds.
- Jordaan noted that low population sizes are more susceptible to environmental change.
- Schultz provided information on river herring population structure which may influence vulnerability to pertubations such as climate change. Schultz noted and provided information that relative to their demography in the 1960s, the breeding populations of

both alewives and blueback herring are more semelparous and younger (Davis and Schultz, 2009; data for blueback herring, Davis Unpubl. data). Schultz wrote that as such changes indicate a reduction in population viability, and some local populations consist mostly of breeding adults returning to their natal site to spawn (Gahagan *et al*., 2012), the connectivity among breeding populations may be limited. Therefore, he concluded that if a local population is depleted its recovery may be slow.

- Wilson noted and provided information after the workshop indicating that current genetic analyses (led by Eric Palkovacs at University of California at Santa Cruz in collaboration with others) may be able to derive information such as estimates of past population size and/or population bottlenecks.
- Gahagan (observer) noted that they have seen variable times for emigration (see Schultz information above) which may be important for climate change assessments, however, duration of emigration of what makes it out into the ocean may be more important to consider.
- Wilson and other participants noted that there is extreme plasticity in these species.
- Lynch noted that the response of river herring abundance to increasing water temperature is complex and modeling the relationship assumes that all variables affecting river herring populations in addition to water temperature (e.g., freshwater habitat, fishing intensity, etc.) do not change from their present conditions.
- Jordaan noted that run counts may not necessarily represent a census or measure flow affects. For example, he noted that if a fish can't get up a fishway, it may just be a measure of how high the flow was that year as they could still be spawning below the dam which might make up for lost migration to these habitats. Jordaan cautioned that

there are other factors (e.g. amount of nutrients) that are going to relate to run count which are not related to climate. As another example, Enterline added that there are places in Maine that have blueback herring, but they are not counted at the fishway.

- Dionne noted that run counts are not a good indication of the population returning, based on information obtained in the Lamprey River in New Hampshire. He noted that in 2007 there was a 200 year flood which denied river herring access to the fish ladder. In 2012, after being fully recruited by age 5, they had record returns to that river. He added that river herring are adaptive and capable of spawning in other areas.
- Stock and Jordaan's comments indicate that one challenge in predicting climate impacts to river herring is that each river might have a unique flow (based on structures present) and temperature.
- Collins noted that flows on rivers with dams in New England are highly variable based on management.
- Collins noted that using air temperature as a proxy for water temperature may be problematic for ground water dominant streams.
- Given some of the data constraints presented at the workshop, Stock noted that an approach to investigate climate impacts would be to use a population that is well observed, develop a life cycle climate model, and then work to extend this more broadly.
- Chase noted that flood frequency can have a negative or positive effect depending on the timing.
- Hare suggested investigating the relationship between large commercial catches and colder periods.

- Hare noted that an important question is how many populations along the coast are facing the inability of adults to return to the ocean.
- It was suggested that one data need was to investigate and compile available information on life stage information, etc. For example, Limburg noted that the Virginia Institute of Marine Science conducted various salinity studies under contract work for power plants to help inform thermal tolerances on different species.

Hypotheses of Anticipated Impacts of Climate Change on River Herring

The workshop participants were asked to think about risk of climate change to river herring, and the relevant components of climate and biology that generates the most risk. The table below was developed based on these discussions and includes additional input from participants following the meeting (Table 4). Considering the discussions at the workshop and additional information provided by participants, NMFS developed a number of hypotheses with supporting and opposing information to inform this issue.

Table 4. Physiological effects of climate change and potential biological impacts to river herring

Physiological Effects Due to Climate Change	**Potential Biological Impacts to River Herring**
Longer, dryer periods	- Habitat loss - Nutrient influx, more hypoxia - Less flow, decreased fish passage - Reduced flow in spring, negative problems in natal homing (due to olfaction issues) - Warmer streams due to less freshwater & less survival in spawning grounds - More saline rivers
Continued warming	- Increase interspecies competition for food based on increased habitat loss in some of the coastal areas - Change prey and predator rates in timing based on changes in timing and migrations - Changes in migration - Change the timing of outmigration - Change the timing of emigration (Change in predators) - Hypoxia impacts (e.g. in nursery areas) - Extirpation of runs based on increased precipitation - Change in range (Extirpation of southern runs) - Change in prey species & habitat types can change invasive species distribution - Reduction of preferred marine habitat - Disease and parasite problems (due to stress in the population) - Assist in the growth of exotic species (e.g. invasive plants) which may contribute to range change\ - Hatching success (e.g. loss of larvae at 20°C which could occur in impoundments)

Sea level rise (Differences between north and south)	- Loss of emerging vegetation, increase sedimentation, eutrophication, degradation of water quality - Loss of habitat south to north (e.g. spawning and foraging areas, wetlands) - Increase tidal flushing (in urban areas) - Shift in nursery areas to freshwater (pending lack of structure)
Less snow	- Less groundwater, warmer streams - Less infiltration with more rain (although dependent on soil and vegetation depth)
Change in channel size	- Limited ability to travel upstream (based on change in flow rate and high velocities; dependent on type of channel and size) - Culverts and passage - Increase sedimentation resulting in limited ability to travel upstream, and egg mortality
Ocean acidification	- Olfaction - Shifts in bottom of food chain (Research needed) - Ability to osmoregulate at the same level & clear carbonic acid which may affect gonad development - They have plasticity so there may be fewer impacts (May depend on location) - Difficult to adapt - More acidic precipitation - Marine issue, not freshwater
Precipitation extremes magnified	- Spawning run success (e.g., juvenile outmigration or adults reaching upstream through fish ladders, natal homing) - Outmigration and emigration timing (e.g. earlier with increased events) - Increased pollution load (associated with change in magnitude of freshwater flows) - Interference with migratory cues - Fish passage issues
Greater annual precipitation and annual streamflow	See related observations provided throughout document
Increased upper ocean stratification	None discussed but see text below
Higher latitudes (~45°) will have fresher water and subtropics having saltier water	See salinity tolerance information provided previously

Although possible impacts on increased upper ocean stratification were not discussed, Wilson provided information from Neves (1981) that river herring and most common at depths < 100 m which may possibly associated with zooplankton concentrations. Wilson also noted that river herring conduct daily migrations (deeper – day, shallower – night) possibly due to plankton. Therefore, it is possible that any impacts on increased upper ocean stratification on plankton could potentially impact river herring.

<u>Hypothesis 1: Climate change will affect freshwater, estuary and marine environments differently which may consequently put alewife and blueback herring migrations out of synchrony with environmental cues that trigger migration</u>

<u>Supporting information:</u>

- Alexander noted that the heat capacity of the water is very large and subsequently it takes much longer for the ocean to heat up compared land. He thought that this could translate to rivers as well, given that air temperature would have a greater impact on shallower water (e.g. in a 10 year average, the river temperature would increase more than the ocean temperature 100 miles offshore).
- Wilson suggested that there is evidence that fish are amassing in the estuaries waiting for suitable environmental conditions before continuing their migration.

<u>Information against:</u>

- Nye noted that there is the potential positive impact if freshwater were to heat up at a faster rate, compared to the marine rate, then when river herring reach the estuary they would not have to wait to enter because the temperature is already up.

<u>Hypothesis 2: Changes in freshwater flows and floods will impact river herring</u>

<u>Supporting information:</u>

- Wilson provided some examples of studies indicating that adult may feed during their spawning run. Limburg suggested that increased freshwater freshets may transport more nutrients that would consequently influence foodwebs.
- Jordaan provided information which suggested that low flow in summer and fall 3 to 4 years prior to a run can impact juvenile growth/survival and outmigration of juveniles

after summary growth, respectively. Additionally, high spring flow in the year of data collection may reduce passage of fish due to a velocity barrier (although some may still spawn below the dam).

- Collins noted that floods affects instream infrastructure and therefore fish passage. Collins also noted that floods directly affect stream habitat via their influence on sediment transport and channel geometry.
- Chase reported an observation with urban streams having degraded substrates. Specifically, he noted that as blueback herring have demersal adhesive eggs, the timing of the flood is important. Therefore, if the flood occurs after the eggs set, he noted that the flood could disperse the eggs which would not be beneficial.
- Stock noted in response to Chase's information that there is possibly a high flow in the spring and low oxygen causing severe hypoxia in the habitat.
- Gahagan noted that legacy affects are being seen in Connecticut.
- Enterline noted that in May in Maine, many of the outmigration routes are through large fishways in dams. If a high volume flood strikes in the spring, it can limit the ability of adults to pass as a large number of impoundments have steep pass fishways.

Information against:

- Based on observations in the Lamprey River in New Hampshire (see above), Dionne noted that river herring are adaptive and capable of spawning in other areas.
- Chase noted that as blueback herring have demersal adhesive eggs, the timing of the flood is important. Therefore, if the flood occurs before the eggs set, he noted that the flood would clear the area which could be beneficial.

Hypothesis 3: Distribution of alewife and blueback herring in the marine environment has shifted from south of Cape Cod north into the Gulf of Maine as a result of climate change

Supporting information:

- Hare noted that ocean temperatures are projected to increase substantially.
- Lynch presented preliminary results from a marine study that shows substantial reduction to habitat with increased temperature.
- From 1960 -2010, a northward shift in the marine distribution of alewife (i.e., the center of biomass in the spring) has been documented (Nye *et al*., 2009).
- Lynch presented information that there have been significant increases in mean latitude of occurrence for both alewife and blueback herring (i.e., northward distribution shifts).
- Rulifson noted that in North Carolina, the fishing industry believes that environmental and water conditions have contributed to low landings following the end of the offshore foreign fishery fleet even with a large quantity of fish in the system (e.g., Winslow, 1989).
- Limburg noted that the ecological theory to moving north is to buffer environmental elasticity. She noted that failed spawning would be generally causing increased elasticity which is an issue.

Information against:

- Wilson thought that there may be a slower northward range shift due to natural homing.

- Lynch showed a northward shift in the migration where the mean biomass is and noted there are numerous explanations; one member of the public wondered if it may mean they are doing better so they are showing up more in the surveys.

Hypothesis 4: Climate change is contributing to a range contraction of alewifes and blueback herring

Supporting information:

- Harris noted that in Florida, blueback herring spawn during the coldest time of the year when temperatures are around 16 to 19 °C. The window in which these temperatures are occurring is getting shorter and shorter.
- Lynch's preliminary results indicated that preferred thermal habitat is projected to substantially decrease in the NEFSC trawl survey area except for blueback herring in the fall.
- From 1960 -2010, Nye *et al*. (2009) found a northward shift in the marine distribution of alewife (i.e., the center of biomass in the spring) and an associated expanded range.

Information against:

- Rohde believed that sea-level rise and higher temperatures would likely create more suitable river herring habitat rather than reduce it in the Southeast.

Hypothesis 5: More frequent precipitation events could impact outmigration and emigration

Supporting information:

- Alexander noted there will be more frequent precipitation extremes.

- Wilson noted that alewife spawn in slow moving rivers (or impoundments) and blueback herring spawn in larger, slow moving rivers (or lakes and small streams).
- Wilson noted that juveniles alewives grow in lakes until densities/food available and/or water flows (egress) trigger outmigration and cited Gahagan *et al.*, 2012 as an example.
- Numerous observations (e.g. Gahagan, Limburg) noted above have reported changes in outmigration and emigration.
- Post noted that a potential change in South Carolina due to water quantity issues is recruitment failure due to severe drought conditions due to dewatering of essential habitat and the absence of seasonally elevated flows which serve as a cue for spawning migration.

Information against:

- None noted/presented.

<u>Hypothesis 6: Climate change could contribute to river herring hybridization</u>

<u>Supporting information:</u>

- Jordaan noted in his presentation that there is limited habitat for these species (as he presented above), so where they intermingle could present situations which result in hybridization.
- If there is continued spatial habitat overlap, there may be more hybrids over time (e.g. occupying the same space for spawning). Regionally different depending on where their spawning locations overlap. They might be more affected by hybridization there as opposed to their spawning areas which are more separated by space. (General group discussion on topic)

- If there is an overlap in timing, there may be an increase in hybrids in the future. As blueback herring arrive later in the season, if there is an observed traction in the time for the onset temperature, then there will be larger periods of time when alewife and blueback herring co-occur. (General group discussion on topic)
- If there is a population contraction in the future, hybridization could increase. (General group discussion on topic)

Information against:

- This is a natural phenomenon that has not been observed before. River herring may be hybridizing more than is currently thought. There is an article from the 1800s that lists more species of river herring than what we have today. (General group discussion)

Hypothesis 7: Ocean acidification could impact river herring more than other sources of acidification

Supporting information:

- Karen Wilson presented on river herring diets which included, but was not limited to, larvae and juvenile feeding on zooplankton and some insects in freshwater. She noted that river herring eat zooplankton (e.g. Calinoid copepods, euphausiids) at sea.
- Hare noted that ocean acidification is increasing which could impact chemical signaling (olfaction) important for river herring. He noted that river herring prey could also be eroded due to calcification.

Information against:

- Hare and Nye noted that ocean acidification in freshwater streams is possible, but is unlikely to match the magnitude in the 1970s. Therefore, Hare noted that acid rain in freshwater systems would give a stronger signal than atmospheric CO_2. Cournane noted that there is significant interest in Nova Scotia about acid rain effects on salmon.

- Nye noted that in estuaries there is hypoxia and increased CO_2 related to estuarine acidification.
- Lynch noted that Kosa and Mather (2001) demonstrated an effect of pH on juvenile abundance in a riverine system. However, Lynch cautioned that the pH effect is most relevant to acid rain, and not climate change induced ocean acidification, because the study was conducted on riverine data.

Data Gaps

For both alewives and blueback herring, the expert panel identified numerous data deficiencies that would otherwise aid in assessing climate change impacts on river herring. These were identified both during discussions throughout the workshop, as well as during a focused discussion on the last day. Data deficiencies identified by the participants included the following (not listed in any particular order):

- Historical level of the population.
- Life history (ocean, habitat, etc.) for all stages and habitat areas (e.g. lake, river, estuary and ocean) using consistent coastwide protocols.
    - For example, in the ocean… Where are they ? What are they doing? Are there mixed school age classes? What depth are they at? What are their predators? When do they get eaten? How many get eaten?
- Habitat use
    - Spawning, foraging, overwintering, early life stage, presence/absence studies

    - Downstream habitat studies to see how salt marshes are utilized
- Assess fish just above the tide zone and below a structure
- Quantitative larval assessment for habitats (e.g. for spawning areas in NC other than the Albemarle Sound)
- Ocean distribution
- Fishing impact in the ocean environment
- Migratory patterns coast wide for all stocks
- Overcome barriers to pull datasets together and coordination across states to fill-in data gaps
- Increased river monitoring, not just at the first dam
- Linking river runs to water temperatures and flow
- Environmental tolerances and thresholds (e.g. temperature) for all life stages
    - Laboratory studies that document biological responses to water chemistry and habitat thresholds
    - Investigate whether these limits change latitudinally.
- River herring sensitivity to climate change variables and projecting these into the future
- Water chemistry and habitat criteria for river herring
- Water quality (including temperature, pH, salinity, contaminants, etc.) and match it up to spawning habitat and early life stage development
- Well-coordinated fishery independent survey network in juvenile habitats
    - Supporting tagging, genetic samples, microchemistry with otoliths, baselines, hydroacoustics, cameras to monitor movements in the estuaries, monitor ocean catch, etc.), prey/predation

- Stock recruitment
- Quantify juvenile emigration
- Data disparity for blueback herring versus alewives Improve long term indices on population status
- Use GIS to develop high resolution elevation models to project inundation due to sea level rise
- Behavior and physiological studies
- Reproduction
- Environmental cues that lead to spawning and migration
    - E.g. use telemetry; combine acoustic work with PIT tag arrays, temperature probes on Northeast lobster traps, ocean gliders)
- Amount of available river herring spawning habitat
- Historical relationships with environmental variables
- Juvenile indices
- Continuous climatologies for marine estuaries and freshwater, as well as migratory habitats)
- Improved monitoring of restocking in the rivers
- River flow and temperature
- Appropriate habitat baselines are important for comparisons
- Homing rates to determine how quickly fish may be able to adapt to change
- Estimates of spawning habitat by watershed (with and without dams)
- Ocean acidification impacts
- Flood magnitudes and frequencies in watersheds impacted by human development

- Flood types and timing looking at recruitment (as egg sets and densities are not always available)
- More information on river herring at the extremes of the range to see the most acute climate change effect (e.g. on blueback herring in the St. Johns River, alewife in North Carolina).
- Additional genetic information (although it was acknowledged that work is ongoing)
- Better methods to count river herring (e.g. Hewitt, 2003) and/or for other areas standaridizing technologies where good counts can be obtained.
    - E.g., hydroacoustic (e.g. North Carolina and Maine via Joe Hightower, USGS), pound net surveys working with fishermen (e.g. North Carolina, Maryland).

Potential Methods to Mitigate the Effects of Climate Change on River Herring

The workshop participants discussed strategies that could mitigate climate change and proactive measures that could be carried out for river herring. This was an impromptu discussion to assist management if climate change was deemed to have an impact on river herring in the future, and additional thoughts were provided following the meeting. However, quantitative analyses are underway to help managers understand the impacts of climate change on river herring.

- Liming to reduce acidification and subsequently repopulate rivers
- Allow time for quantitative assessments to inform management
- Continued habitat restoration projects to improve habitat (shorelines, rivers, and riparian areas → coordinate with city planners)
- Diversity of habitat

- Fish passage improvements
- Water flow management
- Best management practices for watersheds
- Reduce mortality at sea (e.g. avoidance techniques)
- Green infrastructure (working with cities)

Stakeholders Important to Future River Herring and Climate Change Discussions

The workshop participants discussed stakeholders and information important to future river herring and climate change discussions. This was an impromptu discussion to inform future discussion on the issue.

- National Wildlife Refuge (NWR) system
- Fishermen (Pound net users, ocean catch, retired, etc.)
- Conte Anadromous Fish Lab
- People who work on the fish ladders
- Ecological historians
- FERC representatives
- Canada/DFO
- Landscape Conservation Cooperatives (LCC)
- Archaeologists
- Retired scientists
- Conservation officers
- Historical literature (baselines, etc.)
- National Estuary Reserves System

- Linking ocean and river systems with NERACOOS monitoring

Conclusions

While no consensus was sought or reached at the working group meeting, experts provided information and individual opinion on potential impacts of climate change on alewife and blueback herring based on the discussions from the workshop. Habitat and population impacts were both discussed as being important for consideration. Participants discussed many large scale (e.g., change in temperature over the range) and small scale (e.g., forestation impacts on the watershed) impacts on river herring related to climate change. However, it was apparent that research is needed to identify the limiting factor(s) for river herring. For example, although more research is needed on salinity tolerances (e.g., McCormick *et al*., 1997), this may not be a limiting factor compared to others described in this report for river herring based on what is presented here. Limiting factors may vary across the full distributional range for both species. Data gaps were identified by participants to improve future climate change assessments. It is important to note that many participants believed that the conservation of river herring stocks will need to consider numerous factors other than possible impacts from climate change (e.g., fish passage, predation, harvest).

NMFS originally hoped to obtain information on potential impacts by region including information of species, life stage, indicators, potential impacts, and available data/relevant references. Although NMFS did obtain information on each of these categories, the data gaps in the species information was apparent. NMFS will continue with its involvement in the various climate change assessments and other researchers will also be continuing their efforts. It is our hope that this workshop provided information to help facilitate and strengthen these efforts. Additionally, NMFS and others will continue to support much needed research for these species.

Available results from ongoing climate change assessments, information from the workshop (including that summarized in this report), as well as the supporting materials, will be considered by NMFS in determining the potential impacts of climate change on river herring.

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